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Evaluation of Palm Kernel Meal and Corn Distillers Grains in Corn Silage-Based Diets for Lactating Dairy Cows

L. P. F. Carvalho,*† A. R. J. Cabrita,*‡ R. J. Dewhurst,§[1] T. E. J. Vicente,* Z. M. C. Lopes,# and A. J. M. Fonseca*†[2]
*Centro de Estudos de Ciência Animal do Instituto de Ciências e Tecnologias Agrárias e Agro-Alimentares,
†ICBAS, Instituto de Ciências Biomédicas de Abel Salazar, and
‡Faculdade de Ciências, Universidade do Porto, Campus Agrário de Vairão, Rua Padre Armando Quintas, 4485-661 Vairão VC, Portugal
§Institute of Grassland and Environmental Research, Plas Gogerddan, Aberystwyth, SY23 3EB, United Kingdom
#Divisão de Leite e Lacticínios, Estação Experimental, Direcção Regional de Agricultura do Entre-Douro e Minho, Av. dos Templários 421, Apartado 156, 4594-909 Paços de Ferreira, Portugal

ABSTRACT

The effects of increasing levels of solvent-extracted palm kernel meal (SPKM) and corn distillers dried grains (CDG) in corn silage-based diets on feed intake and milk production were examined in 2 experiments. In Experiment 1, 20 Holstein cows averaging 100 d in milk (DIM) (SD = 61.5) at the start of the experiment were utilized in an 11-wk randomized complete block design with 4 treatments in 5 blocks to study effects of increasing levels of SPKM in the diet. During a 3-wk preliminary period, cows were fed a standard diet. At the end of the preliminary period, cows were blocked by 4% fat-corrected milk yield, parity number (primiparous and multiparous), and DIM, and were assigned randomly to 1 of 4 experimental diets. The total mixed ration (TMR) consisted of (dry matter basis) 40% corn silage, 5% coarsely chopped wheat straw, and 55% concentrate. The increasing dietary levels of SPKM were achieved by replacing protein sources and citrus pulp with SPKM and urea (0, 5, 10, and 15% SPKM and 0.06, 0.22, 0.38, and 0.55% urea for SPKM0, SPKM5, SPKM10, and SPKM15, respectively). In Experiment 2, 18 Holstein cows averaging 93 DIM (SD = 49.1) at the start of the experiment were utilized in an 11-wk randomized complete block design with 3 treatments in 6 blocks to study effects of increasing levels of CDG in the diet. The preliminary period lasted for 2 wk. Assignment of cows to treatments was the same as in Experiment 1. The TMR consisted of (dry matter basis) 40% corn silage, 5% coarsely chopped wheat straw, and 55% concentrate. The increasing dietary levels of CDG were achieved by replacing soybean meal and citrus pulp with CDG and urea (0, 7, and 14% CDG and 0, 0.22, and 0.49% urea for CDG0, CDG7, and CDG14, respectively). There were no significant treatment effects on dry matter intake, milk yield, or milk composition in Experiment 1. Inclusion of SPKM tended to increase protein and lactose contents of milk. The SPKM0 diet promoted body weight loss. There were no treatment effects in Experiment 2, except for milk protein content, which was decreased by CDG. Plasma Lys concentration tended to be affected by SPKM and CDG inclusions. Plasma concentrations of 3-methylhistidine and Leu seemed to be related to body protein degradation/synthesis. The feeding of SPKM up to 15% in the diet decreased feed costs without detrimental effects on productive responses and tended to increase milk protein content. The inclusion of CDG in diets based on corn silage and corn byproducts might decrease milk protein content due to an unbalanced supply of AA, particularly Lys.
Key words: corn distillers dried grains, corn silage, lactating cow, solvent-extracted palm kernel meal

INTRODUCTION

Improving the efficiency of use of dietary CP by dairy cow is becoming increasingly important both for reducing potential pollution of dairy farms and for decreasing production costs. Protein rationing for ruminants involves feeding protein first to meet the requirements of rumen microbes (for RDP) and then supplying RUP to meet the MP needs of the animals. Balancing the supply of RDP to the availability of fermentable energy, as well optimizing the diurnal patterns of supply of RDP and fermentable energy are important considerations to maximize the use of RDP and conversion into microbial protein (Mabjeesh et al., 1997; Cabrita et al., 2003). Furthermore, the AA profile of RUP should be considered when formulating diets to not limit the productive response by a deficit in one or more essential AA (NRC, 2001).

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[1]Current address: Agriculture and Life Sciences Division, P.O. Box 84, Lincoln University, Canterbury, New Zealand.
[2]Corresponding author: amira@mail.icav.up.pt

The high costs of the traditional protein sources (e.g., soybean meal) in the European Union, along with the need to reduce feeding costs, are leading many nutritionists to include high levels of vegetable byproducts with moderate protein content in dairy cow diets. Palm kernel meal (**PKM**) is a residue from the oil extraction of the African Palm seed (*Elaeis guineensis*), and is the lowest-priced protein meal (FAPRI, 2005). Depending on the extraction process applied (solvent extraction or expeller pressing), there are 2 types of PKM on the market. The main difference is that the solvent-extracted PKM (**SPKM**) has a lower ether extract content (2 to 3% of DM) than the expeller material (8 to 10% of DM). These byproducts have moderate digestible energy and CP contents and high fiber content (O'Mara et al., 1999; Carvalho et al., 2005); the RUP fraction and its intestinal digestibility is relatively large (Hindle et al., 1995; Woods et al., 2003). Protein of PKM is relatively high in Met and low in Lys and Thr (Van Straalen et al., 1997). Although the European Union-25 account for 88% of worldwide imports of PKM (FAPRI, 2005), this byproduct is normally viewed as a low palatable feed that is generally included in small amounts (<10%) in concentrates for dairy cows. However, the information available on the use of high levels of PKM in diets for Holstein dairy cows is very scarce. This study hypothesized that SPKM could be included in high amounts in dairy cow corn silage-based diets without detrimental effects on productive responses, and allowing the reduction on feed costs (Experiment 1).

Corn distillers dried grains (**CDG**) have commonly been viewed as a high quality protein source for lactating dairy cows (e.g., Owen and Larson, 1991; Liu et al., 2000). Although CDG has good amounts of RUP, as with other corn products, it is typically low in Lys (O'Mara et al., 1997). The hypothesis of this study (Experiment 2) was that the low Lys content of CDG can limit its value as an RUP source in feeding systems based on corn silage, particularly when corn gluten feed represents the major ingredient of the supplementary feed (typical of Northern Portugal).

MATERIALS AND METHODS

The experiments were conducted at the Dairy Unit of the Direcção Regional de Agricultura do Entre-Douro e Minho of the Ministry of Agriculture (Paços de Ferreira, Portugal). This unit has ~50 milking cows with a mean 305-d lactation record in 2002 of 8,760 kg (ANABLE, 2002).

Experiment 1

Twenty Holstein cows averaging 627 kg of BW (SD = 41.5), 100 DIM (SD = 61.5), 2.6 parity number (SD = 1.50), and 34 kg/d of milk (SD = 6.9) were used in an 11-wk randomized complete block design with 4 treatments in 5 blocks. The cows were kept in tie-stalls with individual feed bins in an animal house, and had continuous access to water. During a 3-wk preliminary period, cows were fed a diet comprising (DM basis) 40% corn silage (DM: 30%; NDF: 49% of DM; starch: 23% of DM), 5% coarsely chopped wheat straw (CP: 4% of DM; NDF: 86% of DM), and 55% commercial concentrate (CP: 24% of DM; starch: 23% of DM). The diet was fed as TMR for ad libitum intake, with fresh feed offered twice a day (0900 and 1700 h). At the end of the preliminary period, cows were blocked by 4% FCM yield, parity number (primiparous and multiparous), and DIM, and were assigned randomly to 1 of 4 experimental diets.

Experimental diets contained (DM basis) 40% corn silage, 5% coarsely chopped wheat straw, and 55% concentrate. The whole-crop corn silage was prepared during early October 2001 without the use of a silage additive. The 4 experimental concentrate mixtures were formulated to be isoenergetic and have equal amounts of CP. The increasing dietary levels of SPKM were achieved by replacing sunflower meal, soybean meal, and citrus pulp with SPKM and urea (0, 5, 10, and 15% SPKM and 0.06, 0.22, 0.38, and 0.55% urea; for **SPKM0**, **SPKM5**, **SPKM10**, and **SPKM15**, respectively; Table 1). Corn gluten feed inclusion was also reduced in SPKM15. Urea was included to avoid a large increase in RUP with SPKM inclusion. Diets were fed as TMR for ad libitum intake, with fresh feed offered twice each day (0900 and 1700 h). Throughout the experiment, the troughs were cleaned out each morning and orts collected and weighed. Feed offered was adjusted each week to produce weighbacks of ~10% of amounts fed. During the 11-wk period, samples of corn silage, wheat straw, concentrate mixtures, and orts were sampled on 3 alternate days each week and after oven-DM determination (65°C, 48 h) were composited by 3 periods: preliminary, first 4 wk, and last 4 wk, and submitted for chemical analysis. Cows were milked twice daily at 0700 and 1600 h.

Milk production was measured throughout the experimental period. Milk was sampled at both milkings on 2 consecutive days each week, and proportional composites were analyzed for fat, protein, and lactose (AOAC, 1990; Milkoscan 133, Foss Electric, Hillerød, Denmark). Samples of feces were collected on wk 4 and 8 of the experimental period from each cow at 8-h intervals (0600, 1400, and 2200 h) on 2 consecutive days (the same days as milk sampling) for estimation of diet digestibility using acid insoluble ash as an indigestible internal marker. Whole blood samples were collected 3 h after the morning feeding into heparinized tubes by jugular venipuncture during wk 3 of the preliminary

Table 1. Ingredient composition of the dietary treatments[1]

	Experiment 1				Experiment 2		
Ingredient	SPKM0	SPKM5	SPKM10	SPKM15	CDG0	CDG7	CDG14
	(% of DM)						
Corn silage	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Wheat straw	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Concentrate mixture[2]							
Wheat grain	8.80	9.07	9.35	10.17	6.05	6.05	6.05
Corn gluten feed	22.00	22.00	22.00	17.60	30.25	30.25	30.25
Corn distillers dried grains	—	—	—	—	—	6.88	13.75
Citrus pulp	4.12	2.20	—	—	2.75	1.37	—
Soybean meal, 44% CP	6.60	6.05	4.95	4.67	11.00	5.50	—
Sunflower meal	9.62	6.60	4.40	3.03	—	—	—
Solvent-extracted palm kernel meal	—	4.95	9.90	14.85	—	—	—
Molasses	1.10	1.10	1.10	1.10	1.65	1.65	1.65
Hydrogenated fat[3]	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Urea	0.06	0.22	0.38	0.55	—	0.22	0.49
Bentonite	—	—	—	—	0.55	0.27	—
$CaCO_3$ powder	0.88	0.99	1.10	1.10	0.71	0.88	0.99
Dicalcium phosphate	—	—	—	0.11	0.22	0.11	—
Salt	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Sodium bicarbonate	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Magnesium oxide	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Mineral and vitamin premix[4]	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Cost,[5] %	100.0	98.4	96.6	95.8	100.0	96.7	93.4

[1]Diets are named according to their solvent-extracted palm kernel meal (SPKM) content: SPKM0 = 0%, SPKM5 = 5%, SPKM10 = 10%, and SPKM15 = 15% or according to their corn distillers grains (CDG) content: CDG0 = 0%, CDG7 = 7%, and CDG14 = 14%.

[2]For Experiments 1 and 2, concentrates were prepared in a single batch by Sociedade Descascadora Ovarense, LTD (Ovar, Portugal) and by PROGADO, Sociedade Produtora de Rações, SA (São Félix da Marinha, Portugal), respectively.

[3]Hydrogenated palm fatty acids: Experiment 1, Vetagrialimentar SA (Cantanhede, Portugal); Experiment 2, Desenvolvimento e Inovação Nutricional, SA (Santa Comba Dão, Portugal).

[4]Contained (Experiment 1): 5,000,000 IU/kg of vitamin A; 833,333 IU/kg of vitamin D_3; 16,666 mg/kg of vitamin E; 133 mg/kg of Co; 3,333 mg/kg of Cu; 16,666 mg/kg of Fe; 600 mg/kg of I; 33,333 mg/kg of Mg; 20,000 mg/kg of Mn; 53 mg/kg of Se; and 26,666 mg/kg of Zn; and (Experiment 2): 3,375,167 IU/kg of vitamin A; 675,033 IU/kg of vitamin D_3; 8,350 mg/kg of vitamin E; 3,283 mg/kg of vitamin B_1 (thiamin); 6,625 mg/kg of Cu; 26,633 mg/kg of Fe; 26,758 mg/kg of Mn; 146 mg/kg of Se; 40,300 mg/kg of Zn; and 150 g/kg of S.

[5]Calculated in relation to the cost of the diet without SPKM and CDG inclusion, respectively, for Experiments 1 and 2 (according to feed costs in Northern Portugal in November 2005).

period and wk 4 and 8 of the experimental period (the last day of milk sampling). Tubes were immediately centrifuged at $822 \times g$ for 10 min, and the plasma harvested and stored at −15°C before analysis for urea and AA. Cows were weighed at the same time on 2 consecutive days at the beginning of the study, and on the first and last 2 d of the experimental period. Maximum and minimum daily barn temperatures were recorded throughout the experiment.

Experiment 2

Eighteen Holstein cows averaging 584 kg of BW (SD = 54.8), 93 DIM (SD = 49.1), 2.4 parity number (SD = 1.46), and 32 kg/d of milk (SD = 5.8) were used. This experiment was an 11-wk randomized complete block design with 3 treatments in 6 blocks, and the preliminary period was performed in the first 2 wk. During the preliminary period, cows were fed a diet comprising (DM basis) 40% corn silage (DM: 31%; NDF: 43% of DM; starch: 32% of DM), 5% coarsely chopped wheat straw (CP: 3% of DM; NDF: 77% of DM), and 55% commercial concentrate (CP: 23% of DM; starch: 18% of DM).

Assignment of cows to treatments and management was the same as in Experiment 1. Experimental diets contained (DM basis) 40% corn silage, 5% coarsely chopped wheat straw, and 55% concentrate. The whole-crop corn silage was prepared during early October 2002 without the use of a silage additive. The 3 experimental concentrate mixtures were formulated to be isoenergetic and have equal amounts of CP. The increasing dietary levels of CDG were achieved by replacing soybean meal and citrus pulp with CDG and urea (0, 7, and 14% CDG and 0, 0.22, and 0.49% urea; for **CDG0**, **CDG7**, and **CDG14**, respectively; Table 1). Urea was included to avoid a large increase in RUP with CDG inclusion. Feces were also collected during wk 4 and 8 and blood samples were collected during wk 2 of the preliminary period and wk 4 and 8 of the experimental period (according to the same protocol as experiment 1).

Chemical Analyses

Ground samples (1 mm) of tested supplements, corn silages, wheat straws, concentrate mixtures, and orts were analyzed for ash (AOAC, 1990; method 942.05) and Kjeldahl N (AOAC, 1990; method 954.01). Crude protein was calculated as Kjeldahl N × 6.25. Neutral detergent fiber, ADF, and acid detergent lignin were determined by the detergent procedures of Van Soest et al. (1991) and Robertson and Van Soest (1981), with α-amylase being added, except for wheat straw, during NDF extraction; sodium sulfite was not added. Neutral detergent fiber was expressed without residual ash. For concentrates, NDF, ADF, and acid detergent lignin were determined sequentially. Ether extract was determined by extracting the sample with petroleum ether using a Gerhardt Soxtherm 2000 Automatic (AOAC, 1990; method 920.39). Total sugars were determined by an official Portuguese standard method (Norma Portuguesa-1785, 1986) based on Luff-Schoorl methodology, after extracting sugars with an ethyl alcohol solution. Phosphorus and Ca were determined by gravimetric and volumetric procedures, respectively, as described by official Portuguese standard methods (Norma Portuguesa-873, 1997; Norma Portuguesa-1786, 1985, respectively). Concentrate urea was determined by a spectrophotometric procedure described by an official Portuguese standard method (Norma Portuguesa-3255, 1986). Metabolizable energy content of corn silages was estimated from modified ADF content according to Givens (1990) and ME content of wheat straws was estimated from in vitro digestibility according to Givens et al. (1988). The ME content of concentrates was estimated according to Equation E3 from Thomas et al. (1988). Determination of insoluble ash in hydrochloric acid was done as described by the official Portuguese standard method (Norma Portuguesa-2971, 1985). Starch was analyzed on samples after grinding to pass a 0.5-mm screen by the method described by Salomonsson et al. (1984). Jugular plasma was analyzed for urea (automated chemistry analyzer AUG40, Olympus, Melville, NY) by an enzymatic (urease) method as described by Bauer (1982). Feed AA were determined according to AOAC (2000; method 994.12). Plasma AA on samples collected during the experimental periods were analyzed by ion-exchange chromatography in a ninhydrin-based detection automatic system, using a standard five-lithium-buffer system (LKB 4151 Alpha Plus Amino Acid Analyzer, Produkter AB Research Instruments, Bromma, Sweden) designed for physiological fluid analysis, with L-norleucine as an internal standard. The absorbances were read at 570 and 440 nm to allow Pro quantification. A standard mixture containing 0.5 or 0.25 μmol/mL of each AA was used for calibration (A6282 and A6407, Sigma, St. Louis, MO; Ref. 80203810, Biochrom, Cambridge, UK).

Statistical Analyses

Analyses of covariance of production data and plasma urea, which included repeated measures, were conducted using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Sums of squares were partitioned to covariate, block, treatment, week, week × treatment, and random residual error. Because the interaction week × treatment was never significant ($P > 0.15$), it was removed from the model. Preliminary period variables were used as covariates in each of respective models. Cow within treatment was included as random variable and week was considered a repeated measurement. The first-order autoregressive covariance structure was used according to finite sample corrected Akaike information criterion and Schwarz's Bayesian information criterion (Wang and Goonewardene, 2004). Linear and quadratic contrast statements were included in the model to test the effect of increasing amounts of SPKM and CDG. In Experiment 1, a cubic contrast statement was also included.

Apparent digestibility coefficients and plasma amino acids profile were analyzed using SAS Proc Mixed (SAS Institute). The model included the fixed effects of block, treatment, week, and week × treatment, the random effect of cow within treatment, and random residual error. Because the interaction week × treatment was never significant ($P > 0.15$), it was removed from the model. Week was considered a repeated measurement, using an unstructured covariance structure (Wang and Goonewardene, 2004). Linear and quadratic contrast statements were included in the model to test the effect of increasing amounts of SPKM and CDG. In Experiment 1, a cubic contrast statement was also included. Analyses of BW change data was conducted using SAS Proc Mixed (SAS Institute), including block and treatment as fixed effects and cow within treatment as random effect. Linear and quadratic contrast statements were included in the model to test the effect of increasing amounts of PKM and CDG. In Experiment 1, a cubic contrast statement was also included.

RESULTS AND DISCUSSION

Mean maximum and minimum daily barn temperatures were, respectively, 14.0°C (SD = 2.59) and 7.8°C

Table 2. Experiment 1: Chemical analysis of the tested supplement, individual ingredients, and dietary treatments

		Forage[1]		Concentrate mixture[2]				Diet[2]			
Item	SPKM	CS	WS	SPKM0	SPKM5	SPKM10	SPKM15	SPKM0	SPKM5	SPKM10	SPKM15
DM, %	92.8	30.0	87.0	93.0	93.0	93.0	93.0	67.5	67.5	67.5	67.5
	(% of DM)										
Ash	5.1	3.6	3.7	9.3	9.4	9.3	9.5	6.7	6.8	6.7	6.9
CP	18.9	7.6	3.7	23.0	23.0	23.2	23.5	15.9	15.9	16.0	16.2
RUP[3] (% CP)								28	31	33	35
Ether extract	2.3	2.7	1.0	3.2	3.2	3.4	3.5	2.9	2.9	3.0	3.1
NDF[4]	73.4	46.5	84.2	28.3	27.8	30.4	31.2	38.4	38.1	39.5	40.0
ADF	47.2	28.3	55.3	14.9	14.5	14.8	14.8	22.3	22.1	22.2	22.2
ADL[5]	12.2	3.6	7.0	4.5	4.5	4.9	4.8	4.3	4.3	4.5	4.4
Sugars	3.0	0.4	0.2	6.9	5.4	3.6	3.0	4.0	3.1	2.2	1.8
Starch	0.4	31.1	ND[6]	19.4	21.3	22.9	23.3	23.1	24.2	25.0	25.3
Urea	ND	ND	ND	0.1	0.5	0.8	0.9	0.1	0.3	0.4	0.5
Ca	0.2	0.2	0.3	1.2	1.2	1.4	1.4	0.8	0.8	0.9	0.9
P	0.7	0.2	0.6	0.8	0.7	0.7	0.8	0.6	0.5	0.5	0.6
		(MJ/kg of DM)						(MJ/kg of DM)			
ME		10.5	6.5	11.7	11.6	11.7	11.6	11.0	10.9	11.0	10.9

[1]CS = Corn silage; WS = wheat straw.

[2]Concentrates and diets are named according to the solvent-extracted palm kernel meal (SPKM) content of the diets where they are included: SPKM0 = 0%, SPKM5 = 5%, SPKM10 = 10%, and SPKM15 = 15%. In diets, calculated at 40:5:55 of corn silage, wheat straw, and concentrate mixture, respectively.

[3]Estimated from the NRC (2001).

[4]Ash free; assayed without sodium sulfite; α-amylase was not used for wheat straws.

[5]ADL = Acid detergent lignin.

[6]ND = Not determined.

(SD = 3.57) for Experiment 1, and 25.3°C (SD = 3.91) and 15.6°C (SD = 2.97) for Experiment 2.

Feed Evaluation

The inclusion of SPKM and CDG allowed a reduction in relative feed costs, according to feed costs in Northern Portugal in November 2005 (Table 1). The chemical composition of the tested supplements, individual ingredients, and dietary treatments are given in Tables 2 and 3. The chemical composition of the SPKM used was within the range of variation found in the literature (Hindle et al., 1995; O'Mara et al., 1999; Carvalho et al., 2005). The CDG used had a lower CP content and a higher NDF content than those given both by NRC (2001) and Spiehs et al. (2002), being similar to the batch studied by Carvalho et al. (2005).

The corn silage used in Experiment 1 had a higher starch content than that used in Experiment 2. In both experiments, the formulation objectives were to design diets with ~16% CP, equal content of sugars plus starch, and isoenergetic. The dietary CP content was chosen both because it reflects the common content used for lactating dairy cows on commercial farms, and because a higher dietary CP content does not always increase the productive responses and can contribute to N pollution (McGuffey et al., 1990; Kebreab et al., 2002; Cabrita et al., 2003). Crude protein, urea, and sugars plus starch contents of the diets closely matched the values from the formulation. The estimated dietary ME content was similar within experiments.

Table 4 presents the AA profile (g/100 g of AA) of tested supplements, corn silages, and concentrate mixtures used in these experiments. The AA profiles of the corn silages were quite similar. Increasing inclusion of SPKM had no apparent effect on AA composition of the concentrates mixtures in spite of the decrease on sunflower meal, soybean meal, citrus pulp, and corn gluten feed (only in the SPKM15 concentrate). Conversely, in Experiment 2, replacing soybean meal and citrus pulp with CDG in concentrates promoted a change in AA profile; the most marked being an increase in Ala, Leu, Met, Pro, and Tyr contents, and a decrease in Asp, Ile, Lys, and Phe contents, reflecting the AA composition of CDG.

Feed Intake and Milk Responses

Effects on feed intake, milk production, milk composition, diet OM digestibility, and plasma urea are presented in Tables 5 and 6 for Experiments 1 and 2, respectively. For Experiment 1, there were no treatment effects, except for a tendency for SPKM inclusion to increase protein (P = 0.111) and lactose (P = 0.085) contents of milk. In Experiment 2, there were no treat-

Table 3. Experiment 2: Chemical analysis of the tested supplement, individual ingredients and dietary treatments

		Forage[1]		Concentrate mixture[2]			Diet[2]		
Item	CDG	CS	WS	CDG0	CDG7	CDG14	CDG0	CDG7	CDG14
DM, %	92.5	30.6	90.5	90.3	90.5	90.5	67.4	66.5	66.5
	(% of DM)						(% of DM)		
Ash	5.9	3.6	5.8	10.8	11.0	11.0	7.7	7.8	7.8
CP	27.3	7.6	1.9	23.8	23.7	23.1	16.2	16.2	15.8
RUP[3] (% CP)							32	33	33
Ether extract	8.7	2.8	0.9	3.9	4.4	5.4	3.3	3.6	4.1
NDF[4]	47.4	48.7	79.3	23.8	27.4	30.4	36.5	38.5	40.2
ADF	19.0	28.8	51.1	10.5	10.2	10.3	19.9	19.7	19.4
ADL[5]	4.6	4.3	8.4	2.8	3.1	3.8	3.7	3.9	4.2
Sugars	1.0	0.2	6.7	6.0	5.0	3.5	3.7	3.2	2.3
Starch	6.2	27.4	ND[6]	17.5	18.0	18.7	20.6	20.9	21.3
Urea	ND	ND	ND	0.0	0.4	0.9	—	0.2	0.5
Ca	0.2	0.2	0.3	1.1	1.3	1.1	0.7	0.8	0.7
P	0.8	0.2	0.1	0.9	0.9	0.9	0.6	0.6	0.6
		(MJ/kg of DM)					(MJ/kg of DM)		
ME		10.1	7.0	12.2	12.0	11.9	11.1	11.0	10.9

[1]CS = Corn silage; WS = wheat straw.

[2]Concentrates and diets are named according to the corn distillers grains (CDG) content of the diets where they are included: CDG0 = 0%, CDG7 = 7%, and CDG14 = 14%. In diets, calculated at 40:5:55 of corn silage, wheat straw, and concentrate mixture, respectively.

[3]Estimated from the NRC (2001).

[4]Ash free; assayed without sodium sulfite; α-amylase was not used for wheat straws.

[5]ADL = acid detergent lignin.

[6]ND = Not determined.

ment effects, except for milk protein content, which was decreased by CDG. Diet OM digestibility tended to decrease with CDG inclusion. Dry matter intake and milk yield were similar between experiments, which is consistent with the stage of lactation of cows. However, milk fat content observed in Experiment 1 was lower

Table 4. Amino acid (AA) profile of the tested feeds, corn silages, and concentrate mixtures[1]

	Experiment 1						Experiment 2				
AA	SPKM	CS[2]	SPKM0	SPKM5	SPKM10	SPKM15	CDG	CS	CDG0	CDG7	CDG14
	(g/100 g of AA)										
Ala	4.6	13.9	5.8	5.6	5.6	5.7	7.7	15.8	6.1	7.1	7.7
Arg	15.2	8.0	7.8	8.3	8.6	8.7	5.6	7.1	7.2	5.6	6.5
Asp	9.6	2.2	10.0	10.1	10.0	9.9	7.3	2.1	10.7	9.5	8.2
Cys	1.9	2.0	2.0	2.3	2.2	2.2	2.1	1.7	2.0	2.2	2.1
Glu	20.1	14.4	19.8	19.9	19.9	20.3	17.5	13.7	18.1	18.4	18.2
Gly	5.3	5.7	5.5	5.3	5.2	5.3	4.2	5.9	5.2	5.1	5.0
His	1.9	1.9	2.8	2.7	2.6	2.7	2.6	1.6	3.0	3.0	2.9
Ile	4.2	5.3	4.5	4.6	4.5	4.4	4.1	5.7	4.6	4.4	4.1
Leu	7.3	12.5	8.5	8.5	8.5	8.5	12.6	12.8	8.6	9.4	10.1
Lys	3.4	3.3	4.1	4.3	4.2	4.1	2.6	2.2	4.9	4.4	3.5
Met	2.3	0.3	1.7	1.7	1.7	1.7	2.1	0.8	1.5	1.6	1.7
Phe	5.5	5.2	4.5	4.6	4.5	4.5	5.9	4.7	4.5	4.4	4.1
Pro	3.3	7.6	7.2	6.8	6.8	6.7	8.7	8.8	7.0	7.8	8.5
Ser	4.7	4.1	5.0	4.7	4.8	4.9	4.8	3.5	5.1	4.9	5.0
Thr	3.4	3.7	4.2	4.0	4.0	4.0	3.8	3.8	4.3	4.1	4.2
Tyr	1.6	1.7	0.1	0.1	0.5	0.2	2.8	1.5	0.5	1.5	1.8
Val	5.9	8.1	6.5	6.4	6.4	6.4	5.5	8.5	6.6	6.3	6.3

[1]Concentrates are named according to their solvent-extracted palm kernel meal (SPKM) content of the diets in which they are included: SPKM0 = 0%, SPKM5 = 5%, SPKM10 = 10%, and SPKM15 = 15%, or according to their corn distillers grains (CDG) content of the diets in which they are included: CDG0 = 0%, CDG7 = 7%, and CDG14 = 14%.

[2]CS = Corn silage.

Table 5. Experiment 1: Feed intake, milk production, milk composition, diet OM digestibility, BW change, and plasma urea from the different dietary treatments

	Diet[1]					Contrast (P)[2]		
Item	SPKM0	SPKM5	SPKM10	SPKM15	SEM	L	Q	C
DMI,[3] kg/d	21.5	21.8	21.3	21.6	0.43	0.936	0.982	0.434
Milk yield,[3] kg/d	33.8	33.2	33.4	32.3	0.96	0.353	0.795	0.667
4% FCM,[3] kg/d	29.3	28.4	29.4	28.0	0.48	0.191	0.590	0.054
Fat,[3] %	3.17	3.12	3.24	3.20	0.161	0.760	0.982	0.650
Protein,[3] %	3.00	3.24	3.20	3.23	0.086	0.111	0.298	0.373
Lactose,[3] %	4.67	4.97	5.10	5.12	0.120	0.085	0.244	0.894
Fat,[3] kg/d	1.05	1.00	1.07	1.00	0.032	0.519	0.722	0.121
Protein,[3] kg/d	1.00	1.05	1.05	1.03	0.022	0.316	0.151	0.661
Lactose,[3] kg/d	1.63	1.66	1.67	1.61	0.052	0.860	0.415	0.819
Yield/DMI[3]	1.53	1.53	1.58	1.51	0.032	0.972	0.267	0.303
4% FCM/DMI[3]	1.34	1.32	1.36	1.30	0.028	0.545	0.595	0.192
MP/CPI[3,4]	0.28	0.28	0.29	0.28	0.006	0.960	0.347	0.558
OMD,[5] %	72.7	74.2	70.8	74.9	1.70	0.664	0.440	0.102
BW change, kg	–4.6	28.1	22.6	16.9	8.45	0.144	0.043	0.337
Urea,[3] mg/dL	38.4	42.2	42.6	39.8	1.96	0.598	0.111	0.982

[1]Diets are named according to their solvent-extracted palm kernel meal (SPKM) content: SPKM0 = 0%, SPKM5 = 5%, SPKM10 = 10%, and SPKM15 = 15%.

[2]L = linear, Q = quadratic, and C = cubic effects.

[3]Covariate adjusted.

[4]Milk protein/CP intake.

[5]OM digestibility.

than expected. The orts of this experiment had a higher NDF content than the orts of Experiment 2 (data not presented), suggesting that cows were refusing more wheat straw.

Plasma AA profile was determined to better understand the response of animals to different dietary treatments, particularly in terms of conversion of feed N into milk N. Amino acid concentrations in jugular plasma from cows of Experiments 1 and 2 are given in Tables 7 and 8, respectively. The most striking effects were the linear increase of Ile, Leu, Lys, Orn, and Val with SPKM inclusion in Experiment 1, and the linear increase of Leu and Tyr with CDG inclusion in Experiment 2.

Table 6. Experiment 2: Feed intake, milk production, milk composition, diet OM digestibility, BW change, and plasma urea from the different dietary treatments

	Diet[1]				Contrast	
Item	CDG0	CDG7	CDG14	SEM	Linear	Quadratic
DMI,[2] kg/d	21.6	21.6	21.5	0.70	0.957	0.991
Milk yield,[2] kg/d	33.7	34.4	33.1	1.32	0.751	0.551
4% FCM,[2] kg/d	33.0	33.4	30.8	1.54	0.352	0.445
Fat,[2] %	3.89	3.78	3.63	0.163	0.278	0.939
Protein,[2] %	3.12	2.87	2.87	0.072	0.029	0.227
Lactose,[2] %	4.87	5.00	4.89	0.047	0.782	0.086
Fat,[2] kg/d	1.31	1.29	1.18	0.078	0.334	0.434
Protein,[2] kg/d	1.04	0.98	0.94	0.034	0.389	0.097
Lactose,[2] kg/d	1.61	1.76	1.61	0.065	0.970	0.082
Yield/DMI[2]	1.56	1.60	1.55	0.051	0.866	0.505
4% FCM/DMI[2]	1.51	1.55	1.45	0.060	0.504	0.400
MP/CPI[2,3]	0.29	0.30	0.28	0.007	0.116	0.139
OMD,[4] %	73.8	67.3	68.7	1.90	0.086	0.116
BW change, kg	6.2	18.8	–9.2	12.45	0.404	0.212
Urea,[2] mg/dL	35.4	35.9	33.9	1.67	0.514	0.562

[1]Diets are named according to their corn distillers grains (CDG) content: CDG0 = 0%, CDG7 = 7%, and CDG14 = 14%.

[2]Covariate adjusted.

[3]Milk protein/CP intake.

[4]OM digestibility.

Table 7. Experiment 1: Amino acid concentrations (μmol/L) in jugular plasma from the different dietary treatments

	Diet[1]					Contrast (P)[2]		
AA	SPKM0	SPKM5	SPKM10	SPKM15	SEM	L	Q	C
Abu[3]	16.2	14.1	13.6	17.6	2.37	0.738	0.208	0.780
Ala	209.3	206.6	197.3	221.7	12.54	0.631	0.302	0.481
Arg	61.5	78.2	60.9	77.5	4.84	0.160	0.989	0.006
Asp+Asn	31.0	39.4	30.1	37.2	3.72	0.585	0.860	0.060
Cit	122.2	120.0	135.1	123.4	14.26	0.766	0.734	0.488
Cys	2.7	2.1	3.0	2.7	0.35	0.540	0.647	0.121
Glu+Gln	285.5	306.1	250.6	294.2	12.73	0.614	0.378	0.008
Gly	300.2	283.7	261.7	344.7	27.02	0.365	0.084	0.368
His	35.1	35.1	31.0	38.4	2.49	0.606	0.156	0.175
1-MH[3]	7.7	9.8	6.9	7.9	1.95	0.444	0.447	0.016
3-MH[3]	3.1	2.3	1.0	1.5	0.32	0.001	0.045	0.102
Hyp	8.0	7.6	7.7	8.2	1.51	0.933	0.777	0.984
Ile	83.8	82.1	92.3	101.9	6.22	0.026	0.327	0.619
Leu	100.6	109.1	133.3	138.3	8.59	0.004	0.836	0.352
Lys	62.0	83.8	66.7	78.9	4.28	0.101	0.275	0.003
Met	20.4	20.3	17.6	22.5	1.35	0.563	0.084	0.116
Orn	49.6	60.2	75.1	65.8	6.00	0.037	0.125	0.305
Phe	29.8	26.9	30.5	28.6	3.04	0.998	0.868	0.387
Pro	75.0	76.0	78.8	81.3	6.92	0.503	0.909	0.943
Ser	73.6	75.2	71.1	86.1	4.32	0.098	0.133	0.206
Tau	58.0	74.3	59.3	80.0	8.30	0.198	0.795	0.092
Thr	81.9	85.8	80.0	87.7	5.71	0.656	0.742	0.375
Tyr	35.7	37.4	37.1	39.6	2.93	0.395	0.890	0.708
Val	203.8	211.4	256.3	261.0	14.86	0.005	0.915	0.213
3-MH/Leu	0.031	0.021	0.009	0.015	0.0041	0.002	0.046	0.260

[1]Diets are named according to their solvent-extracted palm kernel meal (SPKM) content: SPKM0 = 0%, SPKM5 = 5%, SPKM10 = 10%, and SPKM15 = 15%.

[2]L = linear, Q = quadratic, and C = cubic effects.

[3]Abu = 2-aminobutyric acid; 1-MH = 1-methylhistidine; 3-MH = 3-methylhistidine.

The results of Experiment 1 are difficult to compare with previous published studies, because we were unable to find studies evaluating PKM for lactating Holstein cows, despite PKM being a common raw material used in formulating diets in the European Union. Interestingly, research has been mainly directed to its use in poultry, pigs, and fish diets (e.g., Perez et al., 2000; Kim et al., 2001; Omoregie, 2001). Although SPKM is normally considered an unpalatable feed, its inclusion had no effect on DMI. However, the possible problems of palatability could have been overcome by using TMR. This study shows that inclusion of SPKM at higher levels than have been used commercially had no effect on productive responses of dairy cows and tended (P = 0.111) to increase milk protein content. This suggests that SPKM inclusion improved the AA status of animals. Indeed, the jugular plasma concentrations of the essential AA Ile, Leu, Lys, and Val increased with the dietary inclusion of SPKM. The effect on Lys concentration is particularly relevant in corn-based diets, in which it is usually one of the first limiting AA for milk production (Nichols et al., 1998; Liu et al., 2000).

The lack of negative effects of CDG on DMI and milk production was also observed by Powers et al. (1995). Owen and Larson (1991) observed a decrease in DMI and milk yield with diets containing 35.8% CDG compared with 18.8% CDG inclusion, and no difference from diets with soybean meal. Other studies (Palmquist and Conrad, 1982; Van Horn et al., 1985) found a reduction in DMI and milk yield with CDG diets compared with soybean meal diets.

The decrease in milk protein percentage for cows fed CDG agrees with previous research (Palmquist and Conrad, 1982; Van Horn et al., 1985; Nichols et al., 1998), and may be attributed to an unbalanced supply of AA, particularly Lys. Indeed, Nichols et al. (1998) found an increase in milk protein percentage, when CDG diets were supplemented with rumen-protected Lys and Met. Liu et al. (2000) observed no improvement in milk yield and composition by feeding blends of protein sources to cows in CDG diets, but such dietary changes improved Lys status of the cows. Despite the inclusion of CDG reducing the Lys content of concentrate mixtures (Table 4), the dietary treatments only tended to affect quadratically the plasma Lys concentration (Table 8).

BW Change

Body weight change from dietary treatments is given in Tables 5 and 6 for Experiments 1 and 2, respectively.

Table 8. Experiment 2: Amino acid concentrations (μmol/L) in jugular plasma from the different dietary treatments

AA	Diet[1] CDG0	CDG7	CDG14	SEM	Contrast Linear	Quadratic
Abu[2]	16.9	11.4	16.0	1.83	0.706	0.040
Ala	184.1	209.6	199.7	21.39	0.621	0.511
Arg	49.2	33.0	45.4	4.55	0.530	0.017
Asp+Asn	27.2	20.2	26.2	3.13	0.819	0.101
Cit	61.6	60.1	69.7	5.12	0.285	0.386
Cys	2.8	3.6	2.9	0.41	0.942	0.258
Glu+Gln	237.0	228.2	239.1	13.78	0.915	0.564
Gly	206.8	214.5	219.5	19.48	0.654	0.955
His	29.5	30.4	31.5	2.35	0.574	0.987
1-MH[2]	5.9	6.4	7.7	2.06	0.355	0.831
3-MH[2]	7.1	2.8	2.7	0.66	0.002	0.029
Hyp	7.4	6.0	6.1	1.82	0.616	0.750
Ile	82.5	72.7	71.3	5.12	0.162	0.518
Leu	88.7	109.2	127.7	5.97	0.003	0.890
Lys	67.6	49.1	56.9	5.89	0.218	0.090
Met	16.9	15.6	17.2	1.75	0.894	0.520
Orn	36.8	27.4	33.8	3.21	0.496	0.059
Phe	27.6	29.2	31.4	2.53	0.313	0.927
Pro	56.0	59.4	63.5	5.54	0.372	0.962
Ser	58.4	58.2	66.4	4.39	0.227	0.450
Tau	70.7	60.1	62.5	6.31	0.390	0.424
Thr	58.4	56.4	53.6	4.28	0.434	0.942
Tyr	35.5	36.4	44.7	2.46	0.037	0.259
Val	170.5	176.7	157.8	9.30	0.364	0.293
3-MH/Leu	0.065	0.039	0.031	0.0111	0.008	0.312

[1]Diets are named according to their corn distillers grains (CDG) content: CDG0 = 0%, CDG7 = 7%, and CDG14 = 14%.

[2]Abu = 2-aminobutyric acid; 1-MH = 1-methylhistidine; 3-MH = 3-methylhistidine.

In Experiment 1, diet SPKM0 significantly promoted BW loss. In Experiment 2, there was no significant effect. Body weight change could be due to a mobilization or synthesis of both protein and fat. Komaragiri and Erdman (1997) indicated that for each unit of change in body energy, 93% was lost or gained as body fat, and body protein accounted for only 7%.

3-Methylhistidine (**3-MH**) is released upon protein degradation, primarily from skeletal muscle (Young and Munro, 1978). Its variation in plasma is partially associated with estimated negative energy and protein balances, and corresponding endocrine and metabolic adaptations (Blum et al., 1985). There is some experimental evidence (Zurek et al., 1995; Kokkonen et al., 2005) that plasma 3-MH progressively decreases and reaches a plateau by 21 d postpartum. The increase of 3-MH, observed after parturition, could result from an enhanced breakdown of skeletal muscle and uterine smooth muscle or another pool (such gastrointestinal tract) with a transiently enhanced turnover rate (Blum et al., 1985). The existence of several pools of 3-MH in the body could limit its value as an index of protein degradation from muscle, and thus of BW change. In both experiments, dietary treatments significantly affected plasma 3-MH concentration in cows after peak lactation (Tables 7 and 8), but only in Experiment 1 was the variation found consistent with BW change.

Concentrations of 3-MH varied in an opposite way to Leu, 3-MH/Leu ratios having significantly decreased with increasing levels of SPKM or CDG. This finding is in agreement with the conclusion of Garlick (2005) that very high concentrations of Leu can stimulate muscle protein synthesis and reduce protein degradation by enhancing insulin secretion as well as the sensitivity of muscle to insulin.

CONCLUSIONS

This study showed that high inclusions of SPKM and CDG in corn silage-based diets did not affect DMI or milk yield of midlactation dairy cows. With current feed prices, this allows a reduction in feed costs. Additionally, the work shows that milk protein content is sensitive to the AA profile of RUP. Milk protein content tended to increase with dietary SPKM inclusion, and significantly decreased with CDG inclusion, agreeing with the pattern of change in plasma concentrations of Lys. Hence, the AA profile of RUP should be considered when formulating diets to improve the conversion of feed N into milk N. The plasma concentrations of 3-

MH and Leu seemed to be related to body protein degradation/synthesis.

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